A DECISION SUPPORT MODEL
FOR ESTABLISHING A
PLASTICS RECYCLING PROGRAM

THESIS

Deven M. Dalcher, GS-11

AFIT/GEE/ENY/94D-1

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GEE/ENY/94D-1

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This research focuses on the development of a decision support model for the establishment of a plastics recycling program. The decision support model focuses on identifying the end-product uses and material specifications first. Once the end-product specifications have been identified, the recycling program can be designed. The model will provide solid waste managers an effective decision making tool to evaluate the economic feasibility of establishing a plastics recycling program.

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THESIS

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of the Air Force Institute of Technology

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Abstract

This thesis focuses on the development of a decision support model for the establishment of a plastics recycling program. The decision support model focuses on identifying the end-product uses and material specifications first. Once the end-product specifications have been identified, the recycling program can be designed. The model will provide solid waste managers an effective decision making tool to evaluate the economic feasibility of establishing a plastics recycling program.

The thesis postulates that the alternative having the highest expected value is the best alternative. In calculating the expected value, the following cost categories are evaluated: collection costs, processing costs, transportation costs, revenue from sales, savings from reduced solid waste collection, saving from reduced solid waste disposal, and intangible costs.

This research also includes a case study to illustrate the use of the decision support model. Although this case study specifically addressed the recycling of plastics on a community level, the model can be applied to the recycling of any material at any operation level. Users of the model can enter site-specific data to determine the cost-effectiveness of their proposed recycling program.

A DECISION SUPPORT MODEL FOR ESTABLISHING A PLASTICS RECYCLING PROGRAM

I. Introduction

This thesis will develop a decision support model for the establishment of a plastics recycling program. The model will focus on identifying the end-product uses and material specifications first. Once the end-product specifications are determined, the recycling program will be designed to achieve those specifications. The model will aid solid waste managers in the establishment of a cost-effective plastics recycling program.

Background

The United States is in the midst of a solid waste crisis. With soaring costs of disposal, increasing amounts of municipal solid waste (MSW), and decreasing disposal options, many communities are faced with the dilemma of how to manage MSW. The cost of managing MSW has drastically increased in recent years. Nationally, the costs of trash disposal are approximately $4-5 billion annually and rising.

In certain parts of the Northeast, tipping fees run $150 per ton and up (Committee, 1992:40). The main factor contributing to the soaring costs of MSW disposal is the decrease of landfill space.

According to US Environmental Protection Agency (EPA) estimates, Americans generate between 160-180 million tons of solid waste per year. In comparison, only 110 million tons of MSW are being generated annually by the European Community (Basta, 1990:43). In the US, the amount of MSW is approximately 1300 pounds per person annually, or 25 pounds per person weekly, or 3.6 pounds per person daily (America's, 1988:2; Leventon, 1992:57). The amount of waste being generated in the US is expected to continue to grow and is projected to increase by over 20 percent by the year 2000 (Forester, 1988:11). The problem of increasing solid waste generation is greatly compounded by the lack of places to dispose of the waste. In 1979, EPA estimates that there were 18500 active landfills and by 1984 there were only 9284, over a 50 percent reduction in only 5 years. By 1987, the number of active landfills had been further reduced to 6584. Today, there are fewer than 6000 active landfills and it is estimated that by the year 2000 another two-thirds will close leaving under 2200 open (America's, 1988:2; American, 1993:17; Forester, 1988:11). This crisis was probably best demonstrated in 1987 when a barge full of solid waste left New York and floated nearly 6000 miles before finding a place to be disposed. In 1988, the EPA reacted by establishing the hierachial goals: source reduction, reutilization, recycling & composting, incineration, and landfilling (Committee, 1992:17). Also in 1988, EPA set national recycling goals to decrease landfilling to 55%, increase incineration to 20%, and increase recycling to 25% within the next four years. Table 1-1 shows the disposal method with relative percentage of the MSW stream.

Table 1-1

EPA National Recycling Goals
(Fleming, 19992:333)

	1970 (%)	1990 (%)	1992 (%)
Landfill	93	80	55
Incinerate	0	10	20
Recycle	7	10	25

In response to the 1988 EPA goals, states, counties, and municipalities have enacted hundreds of laws mandating alternatives to landfilling, setting their own recycling targets, establishing product bans, and recycle content requirements. Angry citizens and environmental groups are seeking out the large waste producers and are propounding a number of remedies. Companies and corporations are changing their ways, seeking approval from "green" consumers. The solution to the solid waste crisis is not a myriad of rules and regulations, but requires the systematic approach of integrated waste management (Committee, 1992:48-49).

Integrated Waste Management.

Integrated Waste Management is a balanced approach to solid waste management through an integrated system using source reduction, recycling, waste-to-energy incineration, and landfilling to safely and effectively manage the reclamation, reuse, or disposal of materials in the waste stream (Council, 1991:81). It involves the use of a variety of disposal and reclamation techniques rather than relying exclusively on one.

Source Reduction. Source reduction uses existing or new technology to reduce the amount of material used to make products, reducing the size of packaging, and recycling scrap material during manufacturing. For example, reduced source packaging can use a thin film rather than a bag inside a carton as a liner. Also, processors can make their products as concentrates reducing the size of packaging (Council, 1991:82). Source reduction conserves natural resources, extends life of landfills, and makes landfilling and incineration safer by reducing or removing toxic substances from the waste stream.

Recycling. Recycling is the process by which materials destined for waste are collected, separated or processed, and returned to the economic market as raw materials or finished products (Council, 1991:82). It is also an economic measure to lower the total costs of solid waste disposal by deferring landfill closure, monitoring, and future replacement costs while taking advantage of the secondary materials market (Lund, 1990:183). Recycling is also important for reducing the needed capacity in waste-to-energy facilities and providing a stable supply of materials to secondary materials processors. In addition, it is a valuable method for individuals to take personal action in addressing the many environmental concerns (Council, 1991:57; Mersky, 1988:104).

Waste-to-energy Incineration. Waste-to-energy incineration uses solid waste as a fuel source to produce heat to generate steam or electricity. The incinerator operates at high combustion temperatures to burn cleaner and minimize the production of ash for disposal. Air pollution control devices remove potentially harmful gases and particles from the stack emission stream. Incineration is an effective method of reducing the total volume of MSW to be landfilled by as much as 90 percent. However, there is still a large public opposition to incineration due mainly to the concern of dioxins. This greatly restricts its role in the integrated waste management program.

Landfilling. Landfilling is the final disposal method used in an integrated waste management program. Landfills are constructed as storage sites, not as composting sites. They are designed to be airtight, dry, and protect wastes from the environment. Researchers have found food stuffs, newspapers, and other materials that had been buried for years which show no signs of decomposition (Fleming, 1992:333). When decomposition does occur, liquids, called leachates, are produced and can contaminate water resources. Also, decomposition can produce methane gas, an explosive hazard and air pollutant. Once a landfill is filled and closed, long-term monitoring must be conducted and then an alternate site must be identified. Landfill operations, closure, and monitoring are very expensive. With stringent environmental regulations and increasing public opposition, replacement sites are decreasing while costs are soaring (Voss, 1989:67).

Municipal Solid Waste Composition

MSW is comprised of a myriad of materials. Paper, metals, and plastics comprise nearly 65 percent of the total waste stream by volume. Figure 1-1 shows the total composition of the MSW stream. Both paper and metals have been recycled for many years, reducing their impact on landfill capacities; however, landfills are still reaching capacity at an alarming rate. This is due in part to the presence of plastics in the waste stream. Source reduction efforts, particularly in packaging of consumer goods, have caused a dramatic increase in the use of plastics in recent years. Plastics represent only 7-9 percent by weight of the MSW stream; however, they occupy a great deal of landfill space relative to their weight, thereby increasing the rate at which landfills reach capacity (Committee, 1992:1). Faced with limited landfill or incineration capacity and increasing disposal costs, city managers are focusing their recycling efforts on plastics in order to get them out of the waste stream.

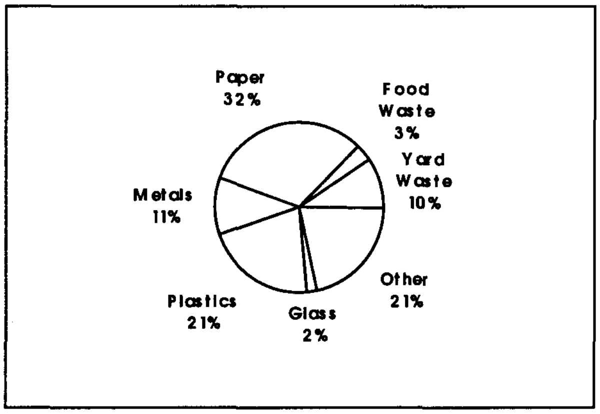


Figure 1-1. Materials in MSW by Volume (American, 1993:5)

Problem Statement

The purpose of this study is to develop and test a decision support model to aid in the establishment of a cost-effective plastics recycling program. The focus of the model will be to identify the end-product uses and material specifications and to develop the recycling program in order to achieve those requirements.

Research Objectives

To achieve the purpose of this study, the following objectives have been established:

1. Determine the various cost categories associated with the management of a plastics recycling program.

2. Develop a decision support model which can be used in establishing a plastics recycling program.

3. Test the model in a case study using simulated data.

Scope/Limitations

There are a variety of methods for the management of solid waste in an integrated waste management system; however, this study focuses on a single management method for only one of many materials in the solid waste stream: establishment of a cost-effective recycling program for plastics.

II. Literature Review

Plastics

Many plastics are derived from fractions of petroleum or natural gas that are recovered during the refining process. This is the most popular and economical method used in making feedstocks for plastics. Coal is another excellent source of plastic feedstocks. Other adaptable materials used in the manufacturing of feedstocks include agricultural oils like castor oil and tung oil derived from plants (Council, 1991:63). From these basic sources come the feedstocks, called monomers. Monomers are small molecules of hydrocarbons. Monomers are put through a chemical reaction, polymerization, which causes them to bond together forming long molecular chains, called polymers or resins. Polymers are a high molecular weight compound containing simple recurring units of monomers. There is a great deal of flexibility in plastic manufacturing for creating a wide range of materials. The way in which monomers are linked together into long chains and the structure of the chains will determine the density of the plastic. Other factors include the length and type of the molecules in the polymer chain. A process of linking different combinations of monomers together, copolymerization, will yield resins with special properties and characteristics (American, 1993:3; Council, 1992:63-64).

From Polymer to Product. Manufacturers produce resins in many forms for further processing. The most popular forms for plastics are granules, pellets, flakes, or powder. Resins can also be produced in the form of liquids. Intermediate processing of resins involves the addition of chemicals, called polymer additives or modifiers, in order to tailor the physical characteristics or properties of the resins to its intended application. Plastics can be dyed, made more flexible, stronger, or more resistant to heat, light, or impact. Processors take these resins and turn them into secondary products (films, sheets, rods, tubes), component parts, or into finished products. Finally, fabricators will further process the secondary materials into end-products.

Types and Applications. Plastics are a composite of materials with distinct properties and forms; however, all plastics fall into one of two categories, thermoplastics or thermosets. Both thermoplastics and thermosets are fluids when they are molded or formed. Thermoplastics are solidified by cooling and can be repeatedly remelted. Thermosets are hardened by an additional process called crosslinking. Unlike thermoplastics, heating will soften the material but will not restore its flowability (Council, 1991:64). Plastics can be furthered divided into categories based upon their resin composition: polyethylene terephthalate (PET or PETE), polyethylene - high density

(HDPE) or low density (LDPE), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS) (Council, 1991:12). These six resins account for nearly 97 percent of all plastics used in packaging (American, 1993:3). The Society of Plastics Industry, Inc. (SPI) has developed a voluntary coding system for plastic containers to identify the material by type. The system was designed to help recyclers in sorting plastics by resin composition. The system recommends the SPI code be placed on or near the bottom of bottles 16 ounces and larger and on containers 8 ounces and larger (American, 1993:12; Council, 1991:12). Table 2-1 identifies each resin by its SPI code and name. It also lists both product and recycled product applications for each resin.

Importance in Source Reduction. Plastics are a very versatile material suitable for a wide range of applications. In many cases, plastics offer better product protection while minimizing the use of resources and creating less waste than alternative packaging (American, 1993:3). Plastics are strong yet lightweight requiring less material in certain packaging applications. For example, plastic film wrappers used for large diaper packs create 50 percent less waste by volume than previous packages. Plastic grocery bags result in about 10 times less waste by volume and weight than paper bags: a stack of 1000 paper bags measures

Table 2-1

Plastic Resin Types
(American, 1993:3-4; Basta, 1990:41; Council, 1991:13-15; Wolfe, 1990:56)

SPI Code	Name	Properties	Packaging Applications	Recycled Packaging Applications
1 PETE	Polyethylene Terephthalate	clarity, toughness, ability to resist permeation of carbon dioxide	bottles - soft drinks, edible oils, liquors, peanut butter	carpets, fiberfill, non-food bottles & containers, geotextiles
2 HDPE	High Density Polyethylene	stiffness, low cost, ease of forming, resistance to breakage	bottles - milk, juice, water, bleach & detergent, motor oil; margarine tubs; grocery sacks	detergent bottles, trash cans, drainage pipes, pails, pallets
3 V	Polyvinyl Chloride or Vinyl	clarity, chemical resistance	heavy-walled pressure pipes, food packaging, chemical packaging	drainage pipes, fencing, siding
4 LDPE	Low Density Polyethylene	clarity, inertness, processing ease, moisture resistance	film products - wrap, bags; flexible tubs - ice cream, margarine	film products
5 PP	Polypropylene	low specific gravity, resistance to chemicals & fatigue	fibers, films, food packaging, screw on caps & lids, automobile batteries	auto parts, batteries, furniture, pails, carpets, geotextiles, industrial fibers
6 PS	Polystyrene	clarity, ability to foam, relative ease of processing, low thermal conductivity	yogurt cups, egg cartons, meat trays, disposable cups, plates & cutlery	insulation board, office equipment, trays
7 Other	Other & Commingled Plastics			landscape timbers, posts, pallets, benches, picnic tables

46 inches in height and weighs 140 pounds while a stack of 1000 plastic bags measures only 3.5 inches in height and weighs only 15.6 pounds. Bottles made of plastics are very durable allowing them to be used again and again. For example, detergents and fabric softeners are being sold in concentrated refills. This utilizes reuse of the original bottle reducing the overall total packaging volume.

Plastic technology continues to improve, resulting in even lighter packaging. Milk jugs made of HDPE weigh only 60 grams today compared to 95 grams in the early 1970's, more than a 50 percent reduction. Today's grocery bags are only 0.7 mils, thousandths of an inch, compared to 1.75 mils in 1984 and 2.3 mils in 1976 (American, 1993:8). Use of plastics in packaging also helps reduce the impact to the environment. For example, plastic grocery bags produce 80 percent less solid waste, emit 70 percent less air pollutants during manufacturing, and require 40 percent less energy to produce than paper bags. According to a 1987 study conducted by Germany's Society for Research into the Packaging Market, if plastics were eliminated from packaging: energy required to produce packaging would double, weight of packaging would increase four-fold, costs of packaging would more than double, and volume of packaging would increase by 250 percent (American, 1993:8-9; Committee, 1992:3).

Plastics in the Packaging Market

As stated earlier, source reduction efforts have lead to a drastic increase in the use of plastics in the packaging of consumer goods. Today, the packaging market consumes approximately 13 billion pounds of plastics annually, tripling over the past 10 years (Stephens, 1987:18). PE, PS, PP, PET, and PVC comprise 97 percent of all the plastics in packaging. Figure 2-1 shows the percentage of each plastic resin used in the packaging market.

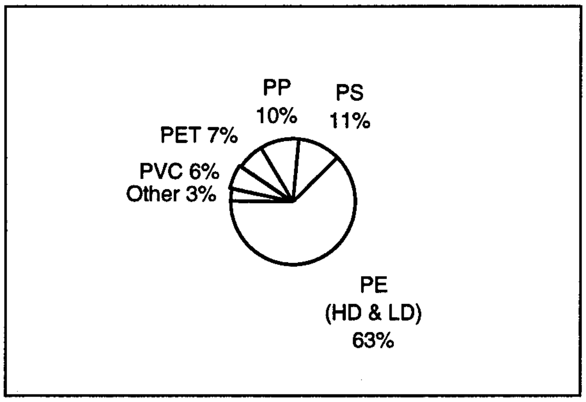
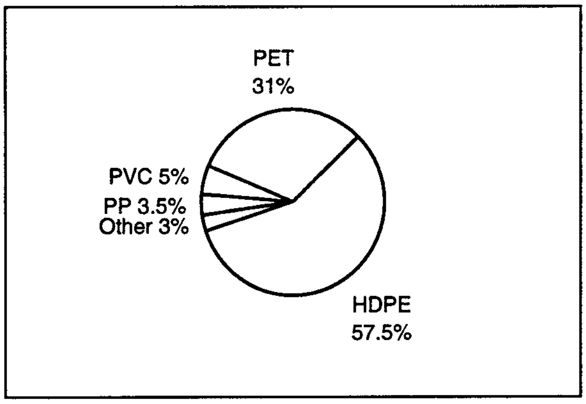


Figure 2-1. Plastic Resins in Packaging (Voss, 1989:69)

Polyethylene is the world's largest selling thermoplastic, with PVC ranked second. Approximately 2.2 billion pounds of HDPE are used annually making it the single largest plastic resin used in blow molded containers (Stephens, 1987:19; Wolfe, 1990:55). HDPE resin represents 57.5 percent of the bottle production market, followed second by PET at 31 percent. Figure 2-2 shows the composition of resins by percent used in the production of bottles.



Bottle = 25.7% plastic packaging

Figure 2-2. Bottles by Resin Type
(American, 1993:4)

Soft drink and milk jugs represent nearly 60 percent of all bottles found in the household making them the ideal target for recycling (Committee, 1992:26). The easiest bottle to identify is the dairy milk jug. Approximately 700 million pounds of HDPE resin are sold to the dairy industry annually, compared to 635 million pounds of all PET bottle resins (Stephens, 1987:48). The average family wastes approximately two plastic containers per day resulting in nearly five billion pounds of waste containers annually (Fleming, 1992:333).

Plastics Recycling in the US

The American Plastics Council estimates there are 6600 communities with some level of plastics recycling program and over 15000 grocery stores with plastic grocery bag recycling (American, 1993:11). The national recycling rate is only 13 percent, well below the EPA goal (Basta, 1990:43). However, the total amount of recovered plastics has increased over the years. One reason for this is because plastics have seen a dramatic increase in use, while new recycling programs are slow to begin and many of the existing programs are still in their infancy. Another reason is many of the recycling programs concentrated on only one or two of the plastic resins. This was due mainly to the market.

In 1990, PET was recovered at a 30 percent rate or 225 million pounds, while 136 million pounds of HDPE was recovered including 49 million pounds of milk jugs (Fleming, 1992:334). In 1991, the total amount of recycled plastics increased to 651 million pounds, a 47 percent increase over 1990. However, only 14 percent of all plastic bottles were recovered.

During 1991, PET soft drink bottles was the leading category at 327 million pounds which represented a 19 percent increase from 1990 levels or 36 percent of total production. HDPE from milk, water, juice, and household chemical bottles and film bags was second with 281 million pounds, a 75 percent growth. Colored HDPE bottles recycling tripled to 92.4 million pounds. PS represented 24.3 million pounds, LDPE 56 million pounds, PP 150 million pounds, and PVC another 7.5 million pounds (American, 1993:10).

The major success of plastics recycling can be found at the community level. For example, a community in Louisiana implemented a recycling program to cover its 114,000 residents and was able to reduce their MSW stream 8 percent by weight and 35 percent by volume. Another community was able to reduce their waste stream by five million pounds in just the first 10 weeks. Parts of the Northeast have been able to reach a recycling rate of 15 percent of solid waste with nearly a 28 percent recovery rate of all soft drink bottles (Committee, 1992:38).

While there are communities with successful programs, there are also those which have failed. Many community recycling organizations are awakening to a rude surprise: mountains of recovered plastics piled up with no profitable place to go. The reason is because they failed to be aware of the capacity of the end markets and the effects of new legislation on those markets. An example of this can be found in Europe.

Plastics Recycling in Europe

The European Community (EC), a commission of 12 European countries, is facing a recycling crisis. The EC proposed a directive on recycling package waste. The central theme of the directive was to harmonize recycling targets across the EC. The directive set ambitious goals: recovery of 90 percent of packaging materials within 10 years, 60 percent of which must be recycled. The net recycling rate of 54 percent would apply separately to each waste stream. In response to the proposed EC directive, Germany launched an aggressive recycling program with the passing of a packaging ordinance in 1991. The target set under the ordinance was to collect 80 percent of all packaging materials by 1995 of which 80-90 percent, depending on the type of material, must be recycled or reused. This target would give an effective recycling rate of at least 64 percent.

The first phase of the ordinance, effective through 1992, required manufacturers and distributors to reclaim packaging materials. The second phase, beginning January 1993, allowed consumers to return packaging back to the retail outlets, which would arrange for recycling. This "take-back" clause was never implemented; instead, the retailers and waste management firms formed a new company, Duales System Deutshland (DSD), to collect the packaging waste directly from the households. Consumers were asked to sort the waste by material type (plastics, glass, metal, paper) using specially provided bins.

sort the waste by material type (plastics, glass, metal, paper) using specially provided bins.

The German consumers have been so enthusiastic that the DSD has appealed for a DM 500 million or $290 million cash injection in order to avoid bankruptcy. DSD can barely afford to collect the projected four million tons of waste, let alone recycle it. Because Germany lacks the recycling capacity, only 124,000 tons, DSD will have to store over 120,000 tons of unwashed plastics waste. About 40 percent of the 400,000 tons of waste plastics will have to be exported. As a result, the fledgling recycling programs in the other European countries have been sent into chaos (Rose, 1993:1492).

The major reason for the failure of the program is due to the lack of planning. The DSD failed to develop the end markets, the requirements of those markets, and the capacity of the markets.

Conclusion

As source reduction efforts continue, new applications for plastics are being found, leading to an increase in the amount of plastics in manufacturing. Due to the decreasing number of landfills and the drastic increase in MSW disposal costs, solid waste managers must consider establishing a plastics recycling program in a cost-effective manner. Recycling is a cost-effective method of reducing the MSW stream, extending landfill life, and reducing disposal costs. It is also important for conserving natural resources. This thesis will suggest a decision support model to aid in the establishment of a cost-effective plastics recycling program based on end-market uses and specifications, for the products that can be manufactured from recycled plastics.

III. Methodology

Introduction

This research will provide a decision support model to aid in the establishment of a cost-effective plastics recycling program by focusing on the end product uses and material specifications. The first section will briefly discuss the principles of decision analysis theory to provide a basic background of the decision analysis tools used to model the problem. The model will be developed and tested in three phases. During Phase I, the cost categories associated with a plastics recycling program will be identified. In Phase II, a decision support model will be developed using decision analysis theory. During the final phase, Phase III, the model will be tested and validated in a case study using simulated data.

Decision Analysis Theory

Decision analysis provides a framework for organizing a complex problem into a structure that can be analyzed. It can identify sources of uncertainty and represent those certainties quantitatively and provide tools for dealing with multiple objectives. Decision analysis also helps in resolving the different perspectives of the decision makers. Decision analysis does not provide solutions. Instead, it is an information source that provides insight about the situation, uncertainty, objectives, and trade-offs, and possibly yields a recommended course of action (Clemen, 1991:2-4). The overall strategy of decision analysis is to structure the problem in smaller and more manageable pieces that can be more readily analyzed (Clemen, 1991:7&9).

The decision analysis process consists of four main steps: identify the problem, identify the objectives and alternatives, decompose and model the problem, and choose the best alternative.

Step 1: Identify the Problem. Identify the problem at hand. It is important that the real problem be precisely identified or else the wrong problem will be analyzed. A surface problem may hide the real issue (Clemen, 1991:5).

Step 2: Identify the Objectives and Alternatives. Identify the objectives and associated alternatives relevant to solving the problem. For example, the objective might be to minimize cost or maximize profit. Careful consideration of all aspects of the problem, including the pertinent objectives, can lead to discovery of hidden alternatives (Clemen, 1991:5&6).

Step 3: Decompose and Model the Problem. Decompose the problem into smaller, more manageable elements and build a model. Decomposing and modeling the problem consists of three steps: model the problem structure, model the uncertainty, and model the preferences (Clemen, 1991:6).

The first step is to model the problem structure. The structure consists of two parts: elements influencing the final outcome and the relationships among the elements.

There are three types of elements: decisions to make, uncertain events, and value of outcomes (Clemen, 1991: 17&34). Decisions to make are elements that the decision maker has complete control over. For example, imagine a farmer with fruit laden trees that are not yet ripe. If the weather report forecasts mild weather, there is nothing to worry about, but if the forecast is for freezing weather, he must decide whether to spend money on protective measures. In this example, the decision to make is whether to take protective actions (Clemen, 1991:17). Uncertain events are elements that effect the outcome, but are not within the control of the decision maker. In the above orchard example, the uncertain event is the weather. The weather may or may not damage the crop (Clemen, 1991:19). After the last decision is made and the last uncertain event is resolved, the value of outcomes is determined. The value of outcome for the orchard example is the amount of profit the farmer makes after deciding whether to protect the crop and the outcome of the weather (Clemen, 1991: 20&21).

In addition to identifying the elements of the problem, the relationships among the elements must be identified. There are two approaches for structuring problems: influence diagrams and decision trees. Each tool has different advantages that complement each other nicely. Influence diagrams provide a graphical representation of the problem. Decisions to make are represented by squares, uncertain events by circles, and value of outcomes by rectangles with rounded corners. The relationships among the elements are represented by arrows, called arcs (Clemen, 1991:34). Decision trees are used to show the details that are hidden with the use of influence diagrams. Decision trees display the possible decision alternatives on branches emanating from squares and possible outcomes of uncertain events on branches emanating from circles (Clemen, 1991:49).

The second step of decomposing and modeling is to model uncertainty. Uncertainty can be modeled by the use of probabilities. One way to model uncertainty is through quantifying the decision makers subjective beliefs and feelings about the uncertainty. Other methods of representing uncertainty is through the use of mathematical models, historical data, or computer simulation (Clemen, 1991:168).

The last step is to model preferences. Most decisions involve some kind of trade-offs which must be modeled. The fundamental trade-off is the level of risk the decision maker is willing to accept. Preferences are modeled using utility functions. Utility functions incorporate the decision maker's risk attitudes (Clemen, 1991:361).

Step 4: Choose the Best Alternative. Choose the best alternative by selecting the alternative with the highest value. Typically, expected value is used to compare the alternatives. Decision analysis is an iterative process. Once a model has been built, sensitivity analysis is performed. Sensitivity analysis is a tool for determining which variables have the greatest impact on the final outcome and deserve more attention. Sensitivity analysis is a tool that can be used to maximize the final value.

Figure 3-1 shows a flow chart of the decision analysis process.

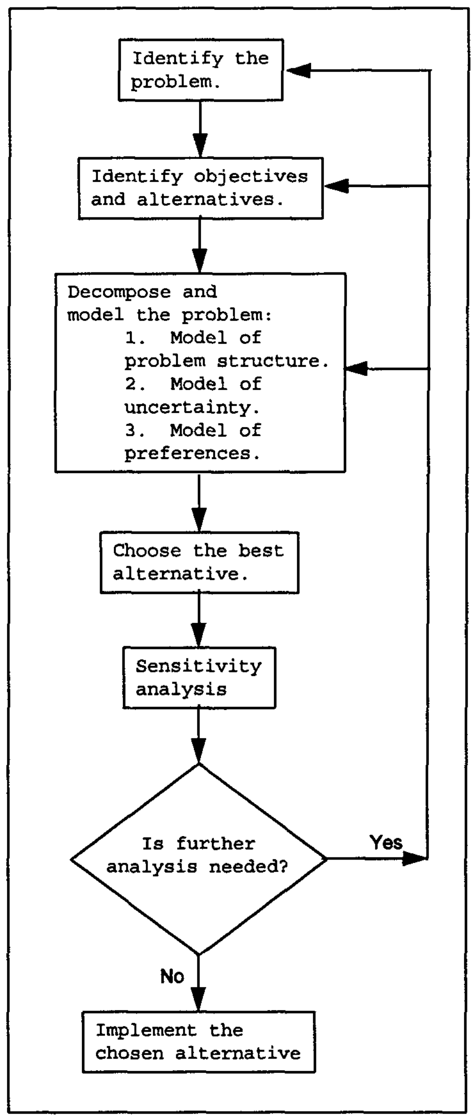


Figure 3-1. Decision Analysis Flow Chart

(Clemen: 1991:6)

Recycling Cost Categories (Phase I)

The following section contains a discussion of each of the cost categories that must be evaluated in determining the total cost of a recycling program. It should be noted that due to variations in local conditions and environmental goals that the cost categories may need to be altered to accommodate the various users of this model. This thesis will use an influence diagram to represent the elements of a recycling program and show their relationships.

Collection Costs. This cost category includes the capital costs of purchasing vehicles and equipment for the collection of materials and also includes the operating costs of the collection program.

Capital Costs (amortized). The capital costs include the cost of purchasing collection vehicles, storage containers, and other capital costs. Storage containers may be drop boxes or household set-out bins or a combination of both depending on the collection program. Household set-out bins include replacement costs and distribution costs. Other capital costs may include specialized equipment such as a plastics densifier or compactor (Council, 1991:47).

Note: In selecting new collection vehicles, managers should look for vehicles that can be economically operated and maintained and yield the highest productivity. The purchase price may appear to be the largest contributing factor to overall costs; however, labor costs typically far exceed the amortized purchase cost of the vehicle (Council, 1991:37).

Operating Costs. The operating costs include the costs of labor, vehicle operations and maintenance, education/promotion, and other operating costs. Cost of labor includes wages, taxes, and benefits and should also include administrative costs. Vehicle operations and maintenance include insurance, registration, fuel, fluids, parts, and repairs. Other operating costs may include overhead, collection and storage equipment maintenance, supplies, tools, and safety equipment (Council, 1991:47).

Figure 3-2 shows the Collection Cost category of the influence diagram. The figure shows the components which comprise the cost of collection and the relationship of each. The Collection Cost category is comprised of operating costs and capital costs. Each of which are comprised of smaller categories.

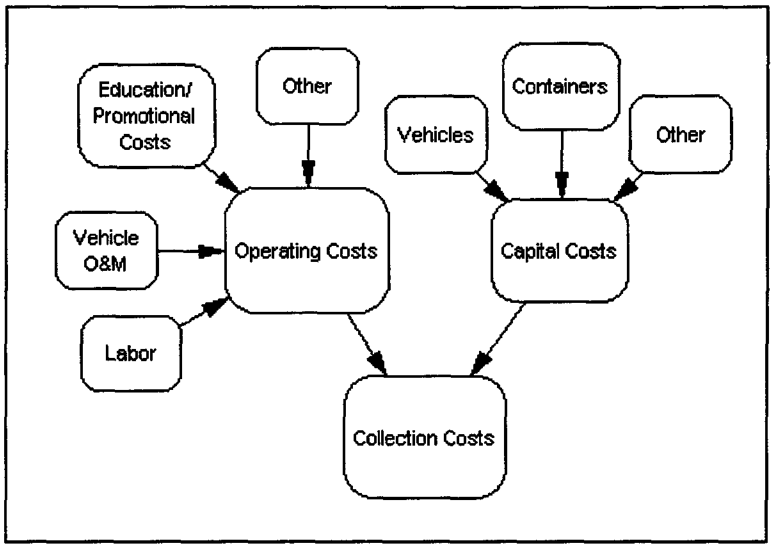


Figure 3-2. Collection Costs

Processing Costs. This cost category includes the capital costs of buildings and equipment for processing of the collected materials and also includes the operating costs of material processing.

Capital Costs (amortized). The capital costs include the costs of constructing or purchasing buildings, processing equipment, and other capital costs. Buildings, including land and site improvements, should either be amortized over 20 years if owned, or annual rental costs if leased. Processing equipment will vary widely depending on the level of processing required, but will typically include conveyors, separators, crushers, and balers. Other capital costs may include scales, forklifts, and other handling equipment (Council, 1991:47).

Operating Costs. The operating costs include the costs of labor, building maintenance, equipment maintenance, and other operating costs. Cost of labor includes wages, taxes, and benefits and should also include administrative costs. Other operating costs may include supplies, hand tools, safety equipment, insurance, utilities, and residue disposal costs (Council, 1991:47).

Note: Labor costs are typically the highest expenditure in a recycling program. Steps should be taken to reduce the labor required. For example, the amortized purchase cost of a state-of-the-art sorting system will be less than the annual costs of a manual sorting system. Not only will the state-of-the-art sorting system reduce labor costs, but it will also increase efficiency and improve end-processing purity levels of the plastic resins (Council, 1991:45).

Figure 3-3 shows the Processing Cost category of the influence diagram. The figure shows the components which comprise the cost of processing and the relationship of each. The Processing Cost category is comprised of operating costs and capital costs. Each of which are comprised of smaller categories.

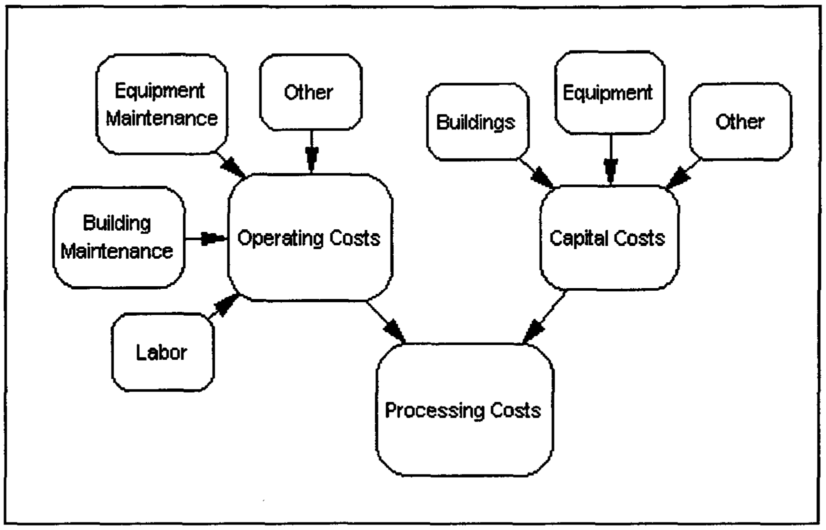


Figure 3-3. Processing Costs

Note: The specifications of the end product will greatly effect the Processing Costs category. The level of processing will depend on the end use of the recycled resin and the required purity level in order to obtain the specified material properties.

Transportation Costs. Transportation costs are the costs associated with delivering the materials to market. These costs are typically paid as a service fee to a trucking company or are incorporated into the negotiated contract (Council, 1991:48).

Figure 3-4 shows the Transportation Cost category of the influence diagram. The figure shows the components which comprise the cost of transporting and the relationship of each. The Transportation Cost category is comprised of a unit cost and the estimated quantity of plastics.

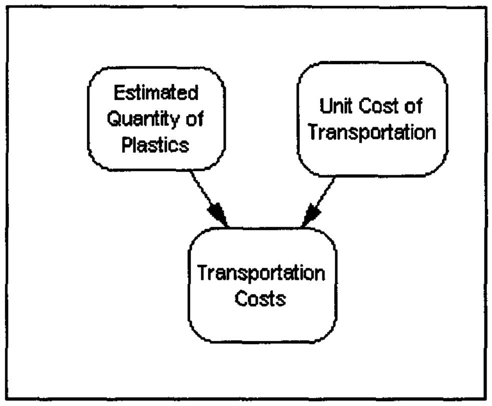


Figure 3-4. Transportation Costs

Revenue from Sales. Revenue is generated from the sale of the recovered plastic resins to end markets. The amount of revenue will depend on the amount of plastics recovered and the negotiated contract prices. The negotiated contract price is a function of the market value and the estimated quantity of plsatics.

Figure 3-5 shows the Revenue from Sales cost category of the influence diagram. The figure shows the components which comprise the revenue from sales and the relationship of each. The Revenue from Sales category is comprised of the negotiated contract price, the market value, and the estimated quantity of plastics.

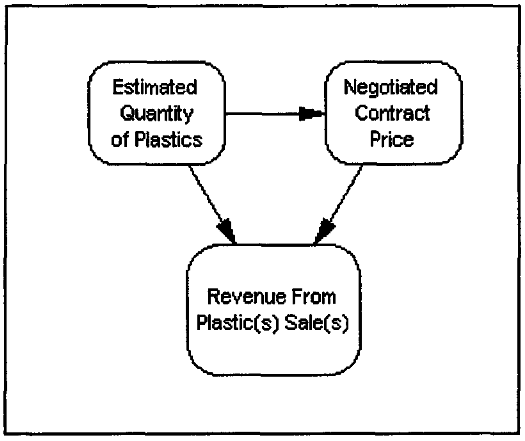


Figure 3-5. Revenue from Sales

Note: The more separation and processing done before shipping will result in higher market value of the plastic resins. Figure 3-6 shows how to increase the value of recycled plastic resins. The figure illustrates the level of separation and processing required in order to obtain the lowest market value, top left-hand corner, to the highest market value, bottom right-hand corner.

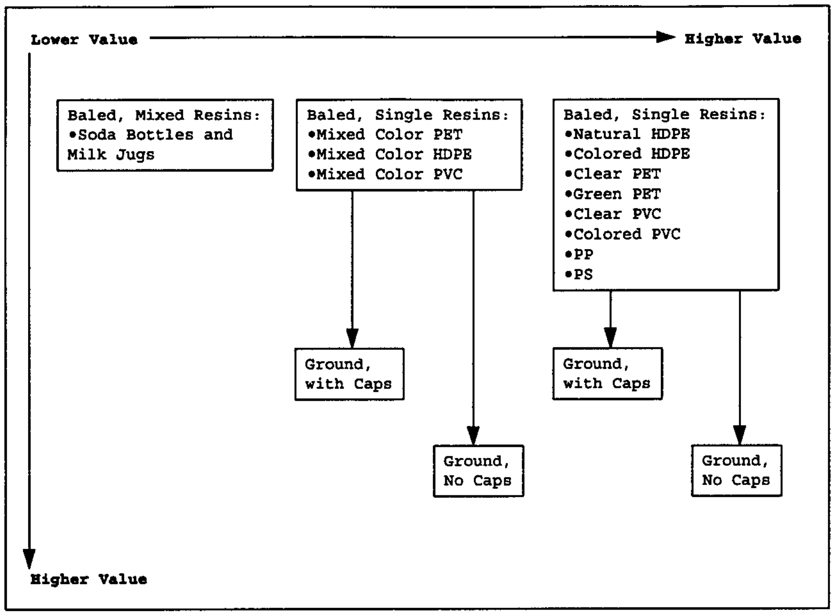


Figure 3-6. Increasing Value of Recycled Plastics (Council, 1991:20)

<u>Savings from Reduced Solid Waste Collection</u>. By recycling plastics from the MSW stream, the total amount of waste is reduced. As a result, refuse collection vehicles are able to remain on their routes longer, covering larger areas. Therefore, the total number of collection vehicles and personnel are reduced, resulting in a savings in equipment and labor costs (Council, 1991:48).

Figure 3-7 shows the Savings from Reduced Solid Waste Collection cost category of the influence diagram. The figure shows the components which comprise the savings of reduced SW collection and the relationship of each. The Savings from Reduced Solid Waste Collection cost category is comprised of the unit cost of collection and the estimated quantity of plastics.

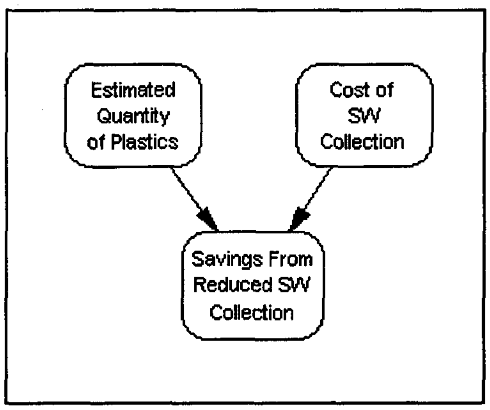


Figure 3-7. Savings from Reduced SW Collection

Savings from Reduced Solid Waste Disposal. By removing plastics from the MSW stream, the total amount of waste destined for disposal is also reduced. The volume of plastics recycled results in the savings of landfill space costs by diverting it from the landfill. Landfill space costs include the amortized capital costs of land, equipment, and land development. The operating and maintenance costs and the estimated closure and post-closure costs should also be included. If the waste is incinerated, the weight of plastics recycled results in the savings of incinerator tipping fees (Council, 1991:48-49).

Figure 3-8 shows the Savings from Reduced Solid Waste Disposal cost category. The figure shows the components which comprise the savings of reduced SW disposal and the relationship of each. The Savings from Reduced Solid Waste Disposal cost category is comprised of the unit cost of disposal and the estimated quantity of plastics.

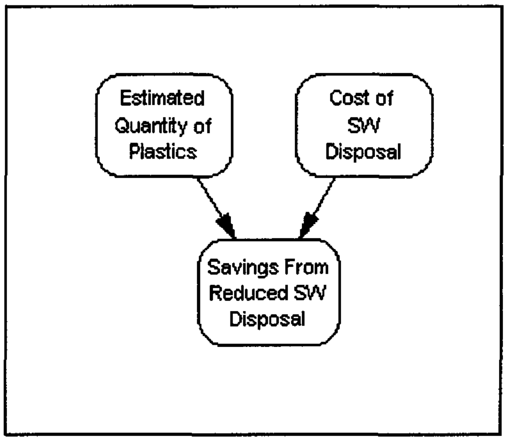


Figure 3-8. Savings from Reduced SW Disposal

<u>Intangibles</u>. Although these intangible costs/benefits are difficult to quantify, they should be incorporated into the decision-making process. The value of these costs can vary significantly depending on local conditions and goals. In some cases they may be the significant factor in the decision process. Some of the intangible benefits associated with a recycling program include: increased public image and attitude, preservation of natural resources, and conservation of energy.

Additional Cost Categories. In developing this model, every attempt was made to identify all cost categories associated with a recycling program. Due to widely varying community goals and policies, it is difficult, if not impossible, to produce a "generic" model. Therefore, if there are additional costs that are specific to a community and are not included, the model should be modified accordingly.

Development of the Decision Support Model (Phase II)

Recycling is a system of integrated steps. In order for it to be successful, all elements of the system must be in place and must be activated by goals and policies to achieve the needs of the community (Committee, 1992:3). There are five primary steps involved in developing a plastics recycling program: conduct a market survey, estimate the quantities of plastics, select a market and negotiate a contract, design a collection and processing program, and implement a community education program (Council, 1991:17).

Step 1: Conduct a Market Survey. Conduct a market survey of all potential markets (handlers, processors, manufacturers) for recycled plastics. The market's processing requirements, contamination restrictions or purity levels, material specifications, and transportation arrangements must be determined (Council, 1991:19-21).

Step 2: Estimate the Quantity of Plastics. Estimate the quantity of recovered plastics in the MSW stream based on expected recovery levels and the number of households serviced by the program. Some factors influencing the quantity of recovered plastics include: community participation, curb-side or drop-off program, and bottle deposit laws. If community participation is high, the amount of recovered plastics will be high. Communities with curb-side collection programs have higher participation and recovery levels than those with drop-off programs. Also, communities in states with beverage deposit laws have recovery levels of certain resins near zero due to the external programs (Council, 1991:25).

Step 3: Select a Market and Negotiate a Contract. Select a market based on the estimated volume of recoverable plastic resins and the current market value and negotiate a contract. The contract should outline the conditions of the material, contamination restrictions, transportation requirements, scheduling issues, and fee structures. A long-term contract has the advantage of guaranteeing a buyer at a set price; however, should the market prices increase, the increased rate would not effect the set price. If large quantities of plastics are expected, consider multiple contracts with more than one market. The advantage is the ensured security of a buyer should one of the markets fail or change specifications. However, the quantity for each market will be smaller which may result in lower prices (Council, 1991:27-29).

Note: These first three steps are the most critical in developing a recycling program. It is vital to find markets for the recovered plastics before beginning a program; otherwise, the program will likely fail no matter how well organized and efficient it is. Many recycling programs have failed or are struggling because the programs were established and operating before identifying their end markets.

Step 4: Design a Collection and Processing Program. Design a collection and processing program based on the type and amount of materials being collected and the market requirements. In designing a collection program, trade-offs between maximizing materials recovery rates and minimizing collection costs must be made. Drop-off collection of recyclables minimizes collection costs, but have very low material recovery rates. Curbside collection programs have higher collection costs, but also have very high material recovery rates.

Curbside collection is the most effective and convenient program and has shown to have significantly higher recovery rates of quality recyclables compared to drop-off programs. The components of a curbside collection program include: commingled or separated materials, pickup schedule, crewsize, household recycling containers, and efficient collection vehicles. Collection of commingled materials is a relatively easy and efficient method; however, it requires a facility for sorting. Commingling reduces the need for compartmentalized collection vehicles and reduces labor costs. The advantage of having residents separate recyclables is the savings in labor costs, but may have an impact on lowering recovery rates. Separation by the driver is more convenient for residents, but will increase labor collection costs. Scheduling the pickup of recyclable materials on the same day as regular trash collection makes it easier for residents to remember and will result in higher participation and recovery rates (Council, 1991:33). Due to labor costs being the largest expenditure, the most cost effective collection program has only one person per vehicle. In most cases, the addition of a second or third crew member does very little to increase collection productivity (Council, 1991:35). By providing household recycling containers, public participation is higher resulting in higher material recovery rates. The recycling containers will increase initial start-up costs, but will make collection easier and more effective. Efficient collection vehicles will allow for collection of the maximum number of households in a day, while reducing operating costs (Council, 1991:33-38).

The design of a materials processing program depends greatly on the end-market requirements. The end-product uses and material specifications will determine the level of processing that must accomplished. In order to meet the material requirements, minimum purity levels of the recycled resins must be achieved. The purity level will determine the technology level and amount of processing equipment required. This directly effects the capital costs of processing.

Step 5: Implement a Community Education Program. Implement a community education program to assure the success of the recycling program. The key to a successful program is public participation and support. Most people are ready to recycle because they view recycling as a means to conserve landfill space and conserve use of nonrenewable resources. It is also a way for them to take personal action in addressing environmental concerns. An effective public education program consists of three stages: an initial announcement, a kickoff campaign, and continued education and reminders. The initial announcement is to inform the public when the program will start. Television and radio announcements, newspaper advertisements, and handbills are effective media of notifying the community. To make a successful start, the public must see, read, and hear about the program. This can be accomplished by conducting a highly promoted kickoff campaign. Coordinate with the press, radio, and television for coverage. Involve local politicians and celebrities. Once the program begins, continue to educate and remind the community on the importance of the program and inform them of the progress by providing results of their efforts (Council, 1991:57-58).

A successful education program includes four key principles: project identity, consistency, clarity, and professional approach. Establish a project identity, such as a logo, to help promote recognition and positive feeling about the recycling program. A consistent plan without major changes will help maximize public participation. Provide instructions that are clear and easy to understand and reinforce them through pictures and graphs. Include specific lists of the materials to include and exclude and how to prepare them. Also, include the collection times and a point of contact for additional information. To capture and maintain community participation ensure all education and promotion programs are conducted with a professional approach. Use of brochures with pictures and graphics, refrigerator magnets, and news coverage are effective approaches. Also, involve local and state officials who are sensitive to the community's needs and concerns (Council, 1991:58-59).

Figure 3-9 shows the entire influence diagram of the decision support model. The figure shows the cost categories of each step, Figures 3-2 through 3-8, and the relationships and influences of each. The expected value (EV) is the sum of the Collection Costs, Processing Costs, Transportation Costs, Revenue from Sales, Savings from Reduced SW Collection, Savings from Reduced SW Disposal, and Intangibles. Each of which are comprised of smaller categories.

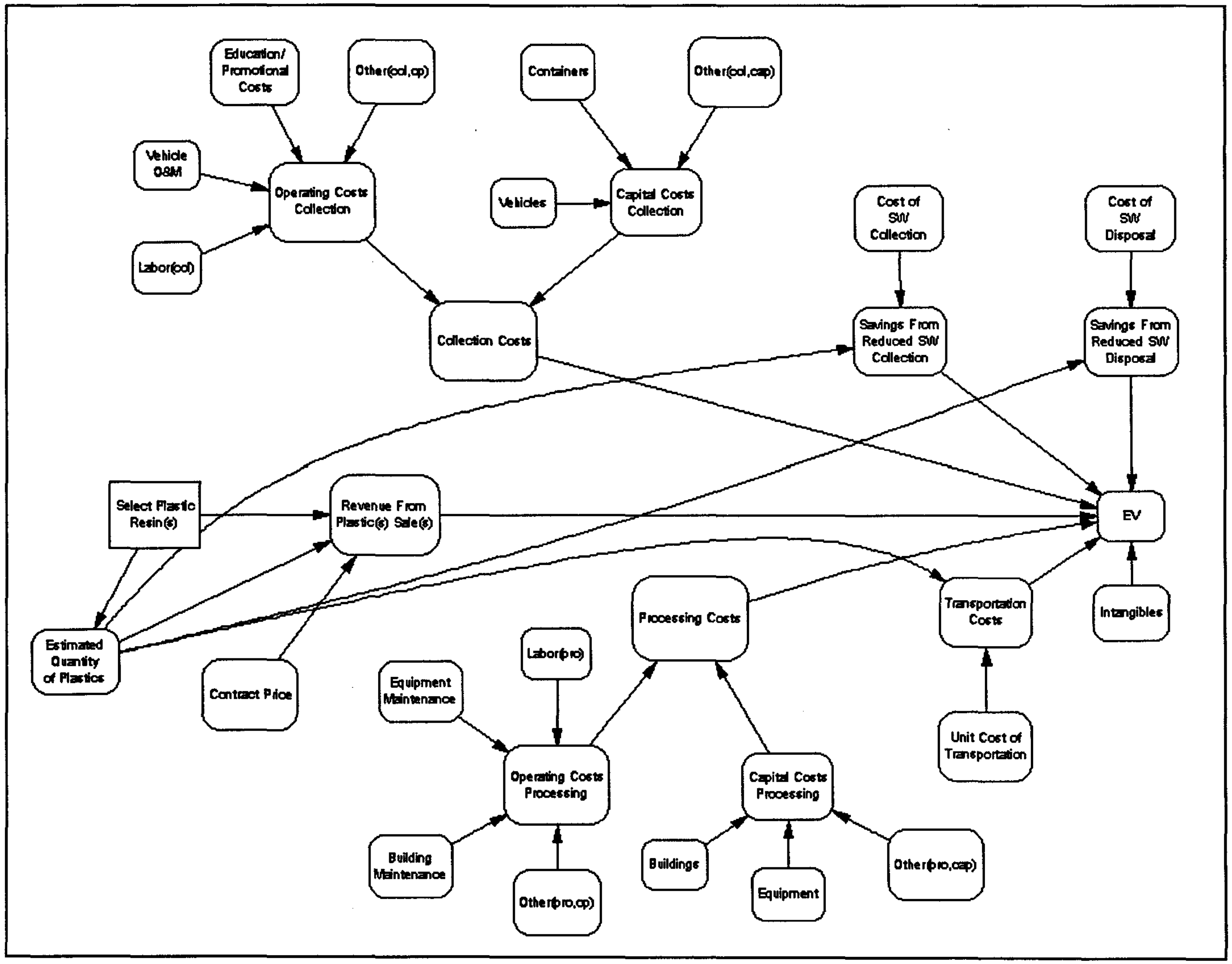


Figure 3-9. Decision Support Model

IV. Analysis and Findings

Introduction

The purpose of the decision support model is to provide SW managers a means of establishing a cost-effective plastics recycling program. This thesis will use DPL™ to conduct the quantitative analysis of the model. DPL™ is a software package designed to build, analyze, and conduct sensitivity analysis of decision problems (DPL, 1992:2).

The first section will describe the types of analysis performed on the model and the relative information provided by each type. The next section will discuss the case study used to validate the model. Finally, the last section will describe the findings of the analysis.

Types of Analysis

There were four types of analysis performed on the model: Decision Analysis, Value Sensitivity Comparison, Value Sensitivity Analysis, and Strategy Region Analysis. Each type of analysis is built-in the DPL™ software package.

Decision Analysis. The Decision Analysis function calculates the expected value and identifies the optimal decision policy (DPL, 1992:303). A Decision Policy diagram displays the expected value of each alternative and identifies the optimal decision (DPL, 1992:307). The optimal decision is the decision alternative with the greatest expected value.

Value Sensitivity Comparison (Tornado Diagram). The Value Sensitivity Comparison function calculates the changes in the output value and optimal policy as one element is varied (DPL, 1992:345). The graphical tool used to show the comparison is a tornado diagram. A tornado diagram shows the range over which the overall value changes as specific elements are adjusted from a minimum to a maximum value (Clemen, 1991:116).

Value Sensitivity Analysis (Rainbow Diagram). The Value Sensitivity Analysis function provides an in-depth look at the effects of varying a single element on the optimal policy and the expected value (DPL, 1992:339). The analysis is performed on the most significant elements identified from the tornado diagram of the Value Sensitivity Comparison. The graphical tool used to show the analysis is a rainbow diagram. A rainbow diagram shows the range over which the overall value changes as a function of the sensitivity variable (DPL, 1992:341).

Strategy Region Analysis. The Strategy Region Analysis is a two-way sensitivity graph that shows the regions for which different strategies are optimal (Clemen, 1991:124).

The graphical tool used to show the analysis is a strategy region diagram. A strategy region diagram shows the range over which the optimal decision policy changes.

Case Study

Users of the model will input specific values representative of their communities for each of the categories in Figure 3-9. However, for the purpose of this analysis, the model was simplified to contain only the major cost categories, the estimated quantity of plastics, and the negotiated contract price. This is due, in part, to the many variables that constitute each major cost category. The purpose of the analysis is to identify the major cost categories that are critical to the final outcome. The effects of the critical categories can be minimized by a number of methods that are location specific.

Figure 4-1 shows the simplified model used for this case study. The figure shows the relationship between each of the major cost categories, the estimated quantity of plastics, and the negotiated contract price. Note that, relative to Figure 3-9, the most significant criteria have been retained for the purposes of the case study.

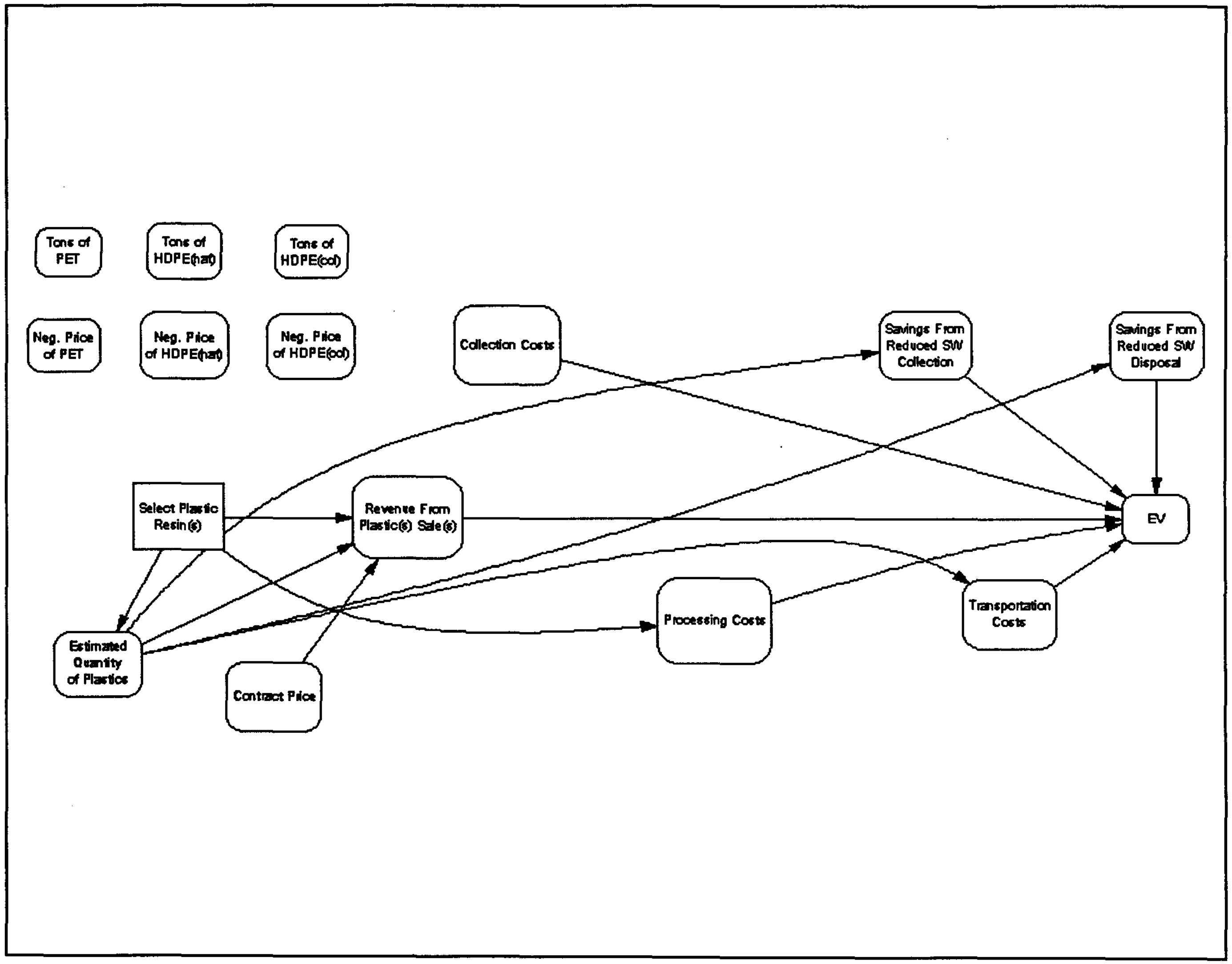


Figure 4-1. Simplified Decision Support Model

Representative numerical values for costs, quantities of plastics, and contract prices based on a typical community (Council, 1991:23; National, 1992:7&10; Fuller, 1994:interview). Examples of the data are in Appendix A, Tables A-1 through A-8. These values were used to validate the decision support model and to provide additional insight about the decision. Input values were a combination of local, regional, and national levels.

The major cost categories were collection costs, processing costs, and transportation costs. These costs were modeled as exponential functions to capture economies of scale. The equations were determined by fitting an exponential equation to each set of gathered data. For example,

$$y = a * b^x + c$$

where;

y = cost category

x = tons of plastic resin

a, b = constants

c = minimum cost level

For example, Figure 4-2 shows the exponential function used for the Collection Cost category. The x-axis represents the tons of plastic resin collected (tons), while the y-axis represents the unit cost of collection ($/ton). The data obtained from the reference is represented by the two boxes. As shown in the graph, the unit cost of collection decreases with the addition of each ton plastic down to a minimum cost level.

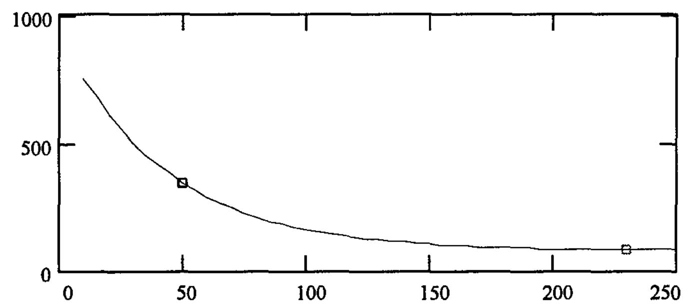


Figure 4-2. Exponential Function of Collection Cost

Table 4-1 shows the constants and minimum cost level for each cost category. The data is categorized by cost category and displays the value of the constants for the exponential function for each cost category.

Table 4-1

Economy of Scale Constants

Cost Category	Constant a	Constant b	Constant c
Collection Costs ($/yr)	844.724	0.97721	80
Processing Costs ($/yr)			
PET	6448.711	0.936	60
HDPE	3027.861	0.941	115
Transportation Costs ($/yr)	10250	0.50	10

The nominal input values used to validate the model are shown in Table 4-2 for a typical community as given by Council, National, and Fuller. The data is categorized by plastic resin type, annual estimated quantity of plastics in tons, and the negotiated contract price in $/lb. Appendix A, Tables A-1 through A-8, shows the complete listing of all the data used to validate the model.

Table 4-2

Input Values

Plastic Resin Type	Estimated Quantity of Plastics (tons/year)	Negotiated Contract Price ($/ton)
PET	80	140
HDPE (natural)	75	100
HDPE (colored)	15	100

Analysis and Findings (Phase III)

Decision Analysis. As stated earlier, the Decision Analysis function calculates the expected value and identifies the optimal decision policy of the model. After the values were input into the model, Decision Analysis was performed.

Figure 4-3 shows the expected value of each option and the optimal decision policy. The results presented in

Figure 4-3 illustrate the expected values (EV) of recycling various combinations of plastics based on the data from Table 4-2. The EV for the combinations of plastics are based on separate processing streams.

For example, recycling of only PET, the item at the top of Figure 4-3, results in an EV of -4984.49 $/yr. Likewise, recycling only natural HDPE, (HDPE_nat_) in Figure 4-3, results in an EV of -12964.8 $/yr. The recycling of only colored HDPE (HDPE_col_) results in an EV of -27081.9 $/yr. Recycling both natural and colored HDPE, represented by (HDPE) in Figure 4-3, results in an EV of -10003.7 $/yr. The higher EV of recycling both types of HDPE is greater than recycling only natural or colored HDPE because of the economy of scale effect. Likewise, the recycling of both PET and natural HDPE (PET_HDPE_nat_) results in an EV of 305.67 $/yr. Recycling both PET and colored HDPE (PET_HDPE_col_) results in an EV of -21393.6 $/yr. The recycling of PET and both natural and colored HDPE (PET_HDPE_) results in an EV of 2393.68 $/yr. Finally, the option of not recycling any plastics, represented by (DO_NOTHING) in Figure 4-3, results in an EV of -32601.7 $/yr. This shows that even though recycling of certain combinations of plastics has a negative EV, it will still save money compared to not recycling any plastics at all.

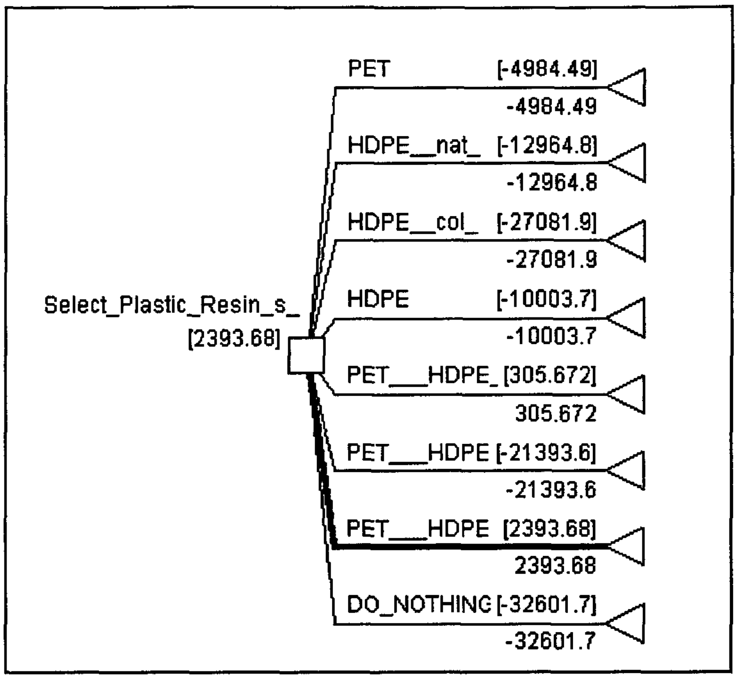


Figure 4-3. Optimal Decision Policy Chart

Based upon the information presented in Figure 4-3, the SW manager should recycle the combination of all three types of plastics. However, input values will differ for each community from those listed in Table 4-2. Therefor, in order to determine how sensitive the decision is for each input value, a value sensitivity analysis was performed.

Value Sensitivity Comparison. As mentioned in a previous section, a Value Sensitivity Comparison calculates the change in the output value and optimal decision policy as one variable is varied. The results are graphed in a tornado diagram. A Value Sensitivity Comparison was performed and the results graphed in a tornado diagram. For the values listed in Table 4-2, Figure 4-4 shows the tornado diagram of the estimated quantity of plastics and the negotiated contract price. The width of the bar reflects the effect the variable has on the expected value as it varies. The wider the bar is, the more significance it has on the expected value. The variables are graphed from the most significant, at the top, to the least significant, at the bottom.

The results presented in Figure 4-4 illustrate the effect on the maximum EV and optimal decision policy, obtained from Figure 4-3, as each variable is varied from its minimum to maximum values. The minimum and maximum values, as suggested by Council, National, and Fuller, for each variable are listed in Tables A-1 and A-2.

For example, as the tons of PET, the item at the top of Figure 4-4, varies from 50 to 110 tons, the EV ranges from -10003.7 to 8884.74 \$/yr. Also, note that varying the tons of PET results in a change in the optimal decision policy, represented by the dark region of the bar, as it varies from its minimum to maximum values. More specifically, when the tons of PET is 50, the EV of -10003.7 \$/yr corresponds to the optimal decision to recycle both types of HDPE, refer to Figure 4-3. Therefor, the SW manager would not consider the recycling of PET. As the tons of PET increases, the decision policy changes to the optimal decision to recycle all three types of plastics. This is because as the tons of PET increases, it becomes economical to include PET in the recycling program.

Likewise, as the negotiated price of natural HDPE, represented by (Neg_Price_of_HDPE_nat_) in Figure 4-4, varies from 0 to 200 $/tons, the EV ranges from -4984.49 to 9893.68 $/yr. Again, note that the negotiated price of natural HDPE results in a change in the optimal decision policy, represented by the dark region of the bar, as it varies from its minimum to maximum values. When the price of natural HDPE is 0 $/ton, the EV of -4984.49 $/yr corresponds to the optimal decision to recycle only PET, refer to Figure 4-3. Therefor, the SW manager would not consider the recycling of natural HDPE. As the negotiated price of natural HDPE increases, the decision policy changes to the optimal decision to recycle all three types of plastics. This is because as the negotiated price of natural HDPE increases, it becomes economical to include natural HDPE in the recycling program.

As the negotiated price of PET (Neg_Price_of_PET) varies from 80 to 200 $/ton, the EV ranges from -2406.32 to 7193.68 $/year. Similarly, the tons of natural HDPE (Tons_of_HDPE_nat_) vary from 50 to 100 tons, resulting in a range of EVs from -1886.6 to 4545.79 $/year. As the negotiated price of colored HDPE (Neg_Price_of_HDPE_col_) varies from 60 to 140 $/ton, the EV ranges from 1793.68 to

2993.68 $/yr. Finally, as the tons of colored HDPE (Tons_of_HDPE_col) varies from 10 to 20 tons, the EV ranges from 1825.35 to 3021.63 $/yr. There is very little impact on the EV by varying the negotiated price or tons of colored HDPE, represented by the narrow bars in Figure 4-4. This is because of the small quantity of colored HDPE available in the waste stream (Council, 1991:23).

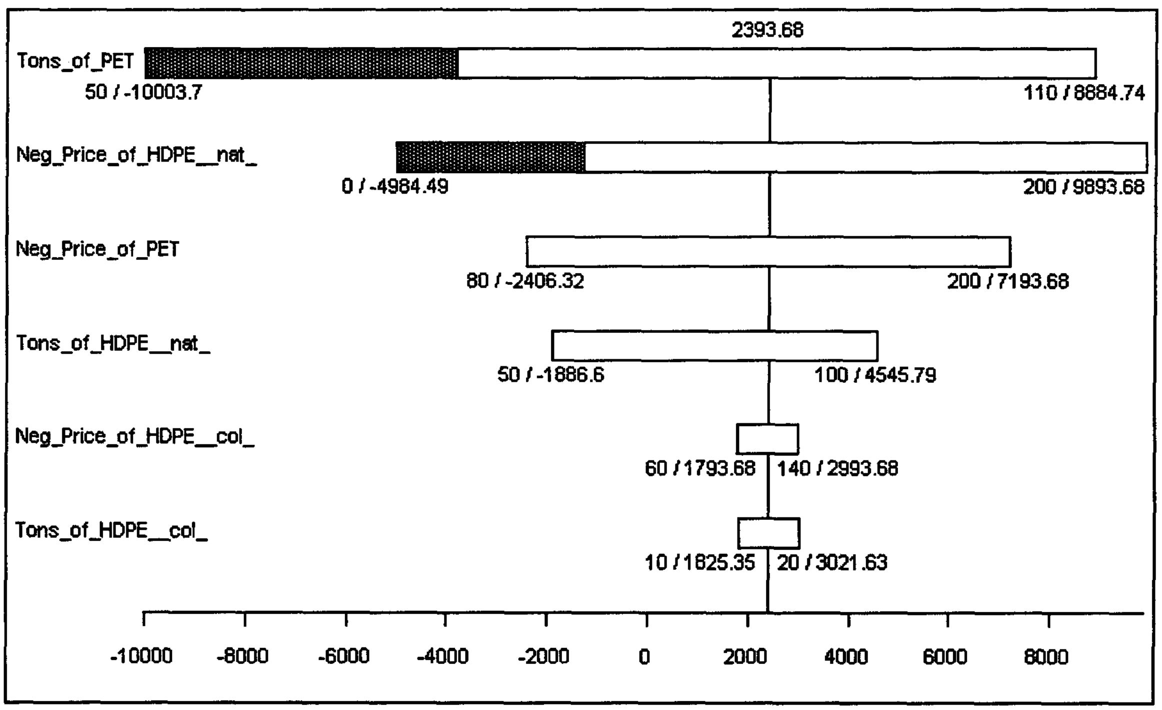


Figure 4-4. Tornado Diagram for Input Values of Table 4-2

Recall from an earlier section that the variables having the greatest effect on the EV warrant further analysis. Based upon the information presented in Figure

4-4, the tons of PET (Tons_of_PET) and the negotiated price of natural HDPE (Neg_Price_of_HDPE_nat_) warrant further analysis. In order to get a more in-depth look at the effects of the variables on the decision policy, a value sensitivity analysis was performed.

Value Sensitivity Analysis. As stated in an earlier section, the Value Sensitivity Analysis function provides an in-depth look at the effect of varying a single variable on the optimal decision policy and on the expected value. A Value Sensitivity Analysis was performed and the results graphed in a rainbow diagram.

Figure 4-5 shows the rainbow diagram of the tons of PET as it varies from 50 to 110 tons. The region with the diagonal cross-hatching represents the optimal decision to recycle both natural and colored HDPE. Recall from Figure 4-4, when the tons of PET is equal to 50 tons, the EV is equal to -10003.6 $/yr, which corresponds to the EV of the recycle both natural and colored HDPE option of Figure 4-3. The decision changes back to the original decision policy of recycle all three types of plastics between 50 and 55 tons, as illustrated by the change in the cross-hatching of the curve in Figure 4-5. This is because as the tons of PET increases, it becomes economical to include PET in the recycling program. The region with the vertical cross-hatching represents the optimal decision policy to recycle all three types of plastic resins. At very low tons of PET, the high unit costs of recycling PET makes it less economical to recycle than the HDPE. The region of the graph below 55 tons is linear; while above 55 tons, the graph is non-linear. This is due to economies of scale at the higher tons.

As the tons of PET approaches 73 tons, the EV changes from a negative to a positive value. This represents the break-even point where recycling revenues off-set recycling costs as illustrated in Figure 4-5. If making a profit is the only concern, the SW manager would have to recycle more than 73 tons of PET.

However, profit is not necessarily the major factor in deciding to start a recycling program. Many communities are faced with limited landfill space. The recycling of plastics from the waste stream is an effective method of extending landfill life. When the intangible costs of public perception and conservation of natural resources are considered, the benefits gained by recycling may off-set the negative EV (loss).

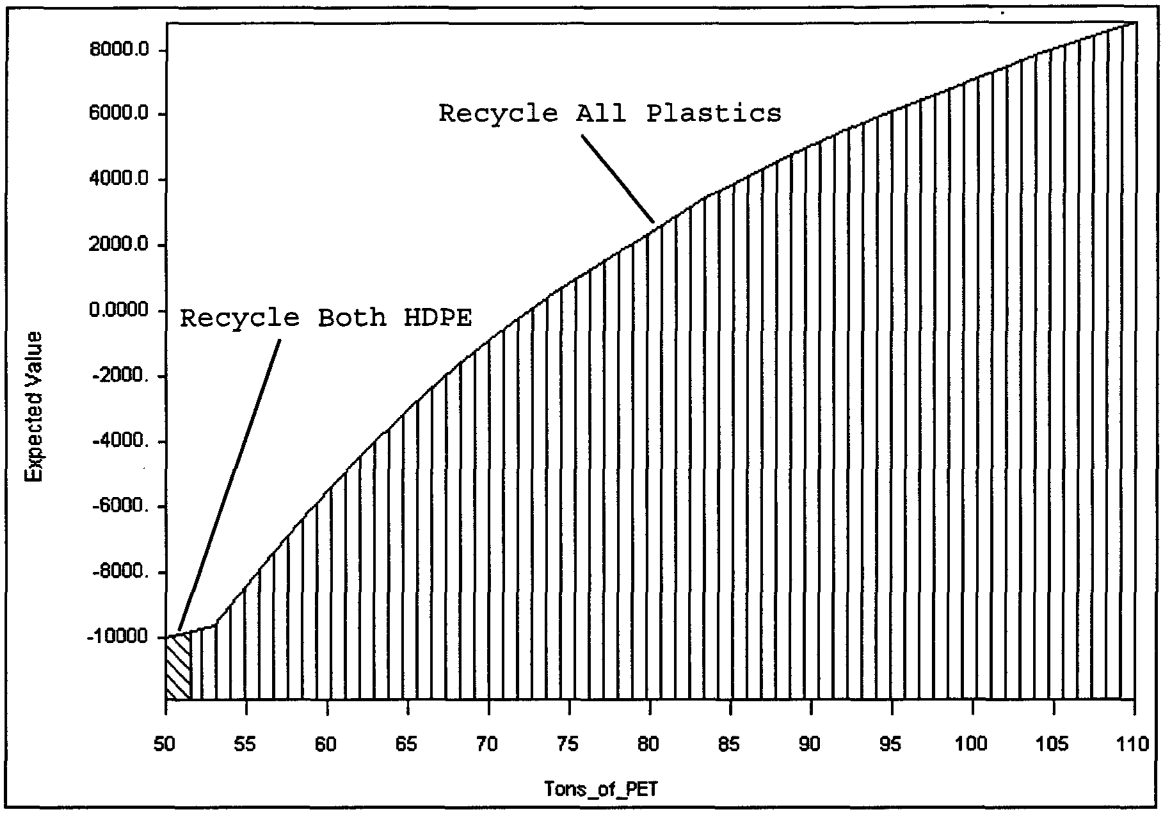


Figure 4-5. Rainbow Diagram of Tons of PET

Figure 4-6 shows the rainbow diagram of the negotiated contract price of natural HDPE as it varies from 0 to 200 \$/ton. The region with the diagonal cross-hatching represents the optimal decision to recycle only PET. Recall from Figure 4-4, when the negotiated contract price of natural HDPE is equal to 0 \$/ton, the EV is -4984.49 \$/yr, which corresponds to the EV of the recycle PET only option of Figure 4-3. The decision changes back to the original decision policy of recycle all three types of plastics between 0 and 10 \$/ton, as illustrated by the change in the cross-hatching of the curve in Figure 4-6. This is because as the negotiated price of natural HDPE increases, it becomes economical to include natural HDPE in the recycling program. The region with the vertical cross-hatching represents the optimal decision policy to recycle all three types of plastic resins. At very low $/ton, recycling of PET is more economical than recycling any HDPE. The graph is linear throughout both regions because there is no economy of scale influence.

As the negotiated price of natural HDPE approaches 70 $/tons, the EV changes from a negative to a positive value. This represents the break-even point of Figure 4-6. If making a profit is the only concern, the SW manager would have to get more than 70 $/ton for natural HDPE. As stated above, profit is not necessarily the major factor in deciding to start a recycling program.

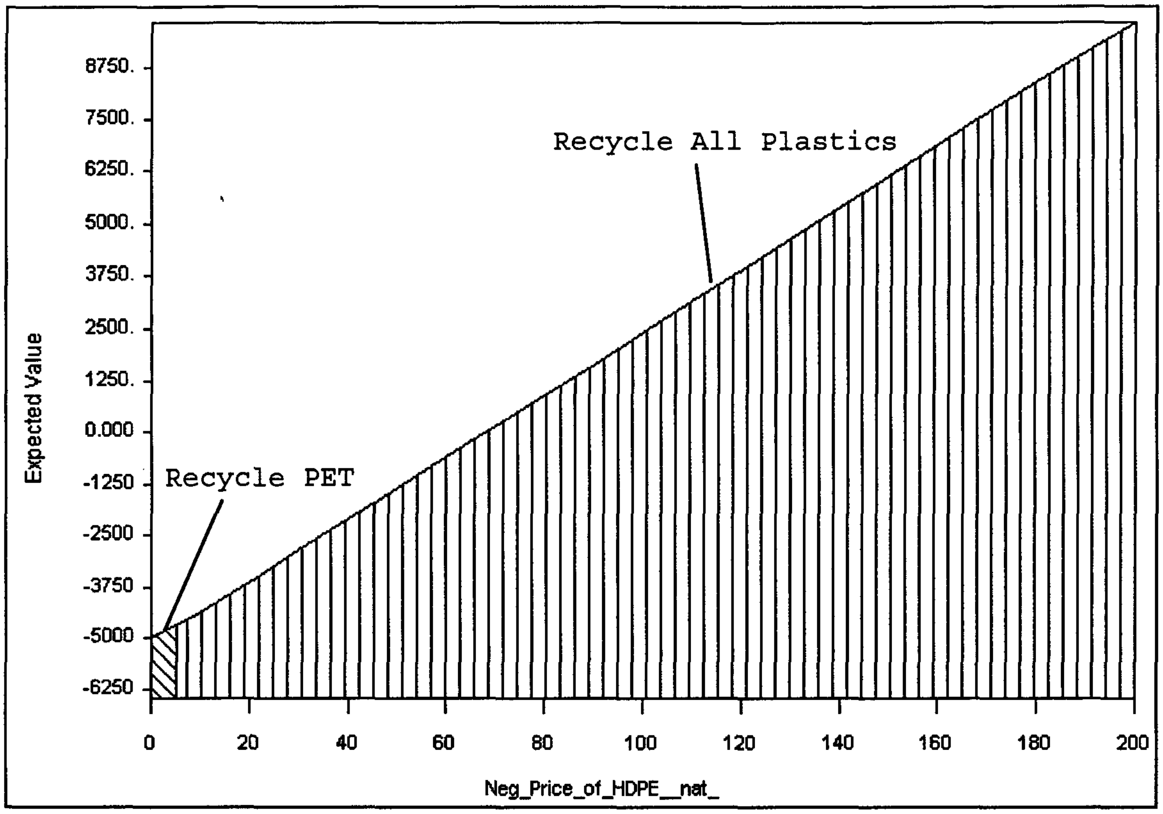


Figure 4-6. Rainbow Diagram of Negotiated Contract Price of HDPE (nat)

<u>Strategy Region Analysis</u>. As stated in earlier sections, a Strategy Region Analysis is a two-way sensitivity graph that shows the regions for different optimal decision strategies. A Strategy Region Analysis was performed and the results graphed in a strategy region diagram. The analysis was performed by conducting a Value Sensitivity Analysis of one variable while fixing the other. The point where optimum decision policy changed was recorded.

For the data in Table 4-2, Figure 4-7 shows three regions of optimal decision policy. The dark region represents the optimal decision policy to recycle PET only, the gray region represents the decision policy to recycle both natural and colored HDPE, and the white region represents the decision policy to recycle all three types of plastics. The following points were chosen to help illustrate the changes in the decision policy. At point A, 60 tons of PET and 20 $/ton for natural HDPE, the optimal decision is to recycle both types of HDPE. This is because at very low tons, it is not economical to recycle PET. If the tons of PET increases to 80 tons keeping the price of natural HDPE at 20 $/ton, point B, the decision policy changes to recycle all three types of plastics. This is because as the tons of PET increases, it becomes more economical to include PET in the recycling program in order to start to capture the economies of scale.

At point C, the tons of PET increases to 100 tons, while the price of natural HDPE remains at 20 $/ton. This point corresponds to the decision policy of recycle PET only. As the tons of PET increases further, it becomes the most economical to recycle because the small savings generated from recycling HDPE does not offset its costs. If the negotiated price of natural HDPE increases to 50 $/ton keeping tons of PET at 100 tons, point D, the optimal decision policy changes to recycle all three types of plastic resins. This is because the recycling of all three types of plastics maximizes the effect of the economies of scale.

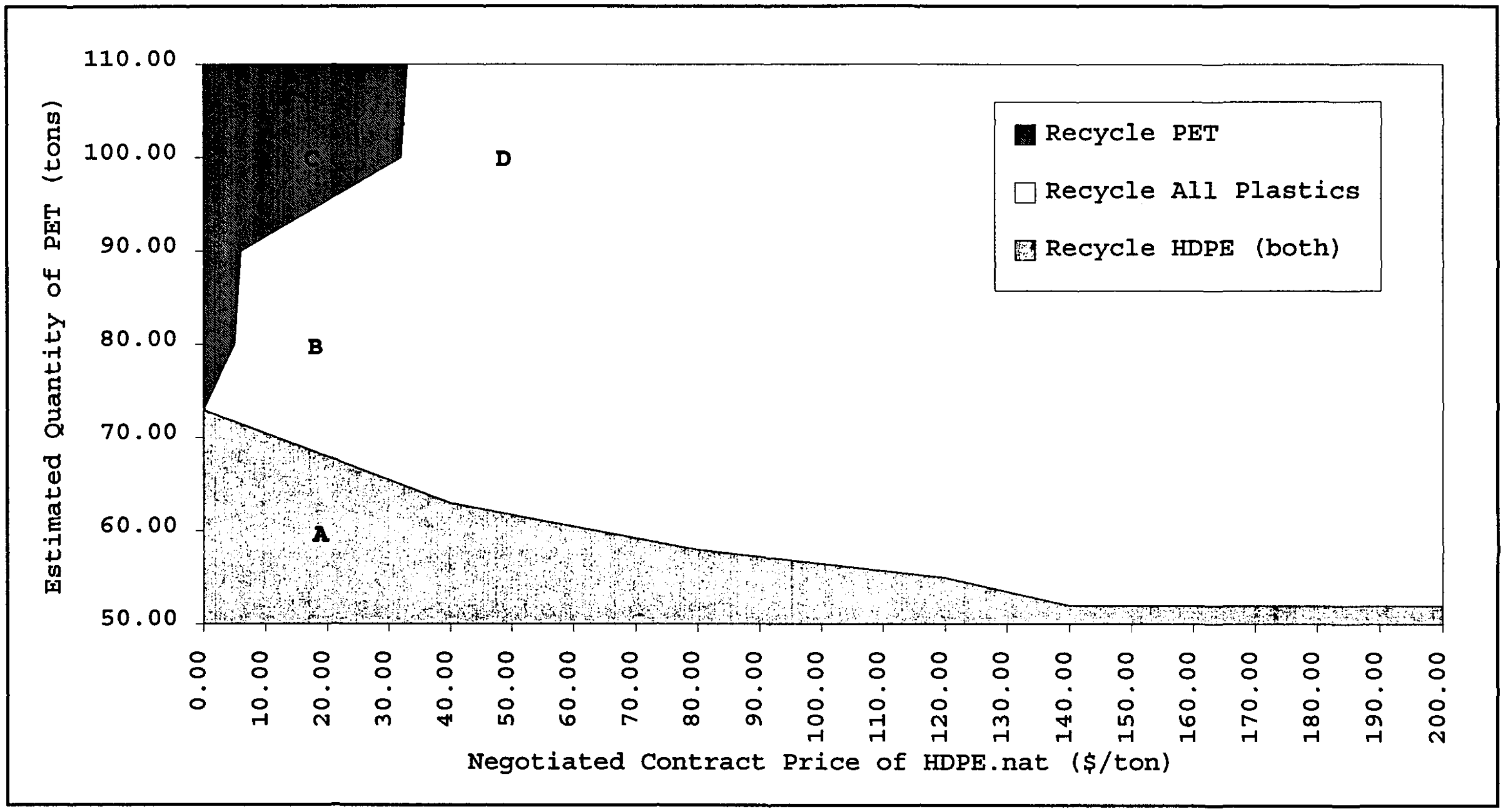


Figure 4-7. Strategy Region Graph

V. Conclusions and Recommendations

Overview

The United States is in the midst of a solid waste crisis. With soaring costs of disposal, increasing amounts of municipal solid waste (MSW), and decreasing disposal options, many communities are faced with the dilemma of how to manage MSW. Faced with limited landfill or incineration capacity and increasing disposal costs, city managers are focusing their efforts on recycling plastics in order to get them out of the waste stream.

The purpose of this study was to provide SW managers with a tool to evaluate the economic feasibility of establishing a plastics recycling program. This thesis developed a decision support model using the DPL™ software package. The end-product uses and material specifications influenced the outcomes of the model and the design of the recycling program.

The model uses Decision Analysis Theory and built-in functions of DPL™ as a means of evaluating the optimal decision policy and to provide further insight into a plastics recycling program. The decision support model considered the following cost categories: collection costs, processing costs, transportation costs, revenue from sales, savings from reduced SW collection, savings from reduced SW disposal, and intangibles. These cost categories account for the costs associated with the recycling of plastics. Values for a representative community were used to validate the decision support model and to provide additional insight about the decision. Input values were based on a combination of local, regional, and national levels. The collection costs, processing costs, and transportation costs were modeled as exponential functions to capture economies of scale.

Conclusions

There are several conclusions that can be drawn from the analysis of the case study. First, the analysis shows the MSW manager that considering the end-product uses and material specifications upfront will help assure the success of a recycling program compared to the traditional ad-hoc recycling program.

Second, the optimal decision policy was identified by the maximum expected value. This case study concluded that recycling all three plastic resins (PET, natural, and colored HDPE) was the optimal decision; however, this may not be the optimal alternative for every recycling program. Additionally, comparison of all cases of expected values for the recycling program exceed the expected value of not establishing a recycling program. This indicates that while a recycling program does involve costs, the costs can be partially offset by properly choosing the correct combination of plastics to be recycled.

Third, sensitivity analysis comparison determined the effect a variable has on the expected value. For this case study, two variables, Tons_of_PET and Neg_Price_of_HDPE_nat, not only significantly impacted the expected value, but they also resulted in a change in the optimal decision policy. These variables warrant additional attention by the SW manager.

Finally, a strategy region analysis was performed to show the range over which the optimal decision policy changes. For this case study, the strategy region graph shows three regions of optimal decision policy. One region represents the optimal decision policy of recycle PET only, another represents the decision policy of recycle both natural and colored HDPE, and the final region represents the decision policy of recycling all three types of plastics.

Recommendations for Future Research

Although the decision support model is very useful in its present form, future research is needed to adapt the model to more common software packages. The model could be coded into an interactive program or into a spreadsheet format.

Future research is also needed to develop a database that relates material specifications and performance criteria of recycled plastics to processing requirements and purity levels.

The decision analysis principles utilized in this research proved to be a sound method to analyze and compare the alternatives associated with the case study. These principles could easily and effectively be applied to recycling programs involving other materials.

Appendix A

Appendix A defines the variables used in the decision support model and lists the case study values used to validate the model. The variables and their values where entered into an EXCEL™ spreadsheet and linked to the DPL™ model.

Table A-1

Estimated Quantity of Plastics
(Council, 1991:23)

		lbs/household/yr				tons	
	low	high	ave		ave	low	high
PET	5	11	8		80	50	110
HDPE (nat)	5	10	7.5		75	50	100
HDPE (col)	1	2	1.5		15	10	20

Number of Households = 20000

Table A-2

Negotiated Contract Price
(National, 1992:10)

		$/ton	
	ave	low	high
PET	140.00	80.00	200.00
HDPE (nat)	100.00	0.00	200.00
HDPE (col)	100.00	60.00	140.00

Table A-3

Revenue from Plastic Sales

		$	
	ave	low	high
PET	11200.00	4000.00	22000.00
HDPE (nat)	7500.00	0.00	20000.00
HDPE (col)	1500.00	600.00	2800.00
HDPE	9000.00	600.00	22800.00
PET & HDPE (nat)	18700.00	4000.00	42000.00
PET & HDPE (col)	12700.00	4600.00	24800.00
PET & HDPE	20200.00	4600.00	44800.00
	11542.86	0.00	44800.00

Revenue = Est. Quantity * Contract Price

Table A-4

Collection Costs
(Fuller, 1994:interview)

		$	
	ave	low	high
PET	17086.54	16158.29	17337.67
HDPE (nat)	17242.65	16423.74	17337.67
HDPE (col)	10166.53	7508.01	12253.76
HDPE	16747.04	15974.47	17509.84
PET & HDPE (nat)	16074.27	16423.74	18200.86
PET & HDPE (col)	16580.27	15883.85	17509.84
PET & HDPE	16451.72	16158.29	19367.52
	15764.15	7508.01	19367.52

Table A-5

Processing Costs
(National, 1992:7)

		$	
	ave	low	high
PET	7397.95	6842.00	14809.60
HDPE (nat)	10998.66	10998.66	12987.48
HDPE (col)	19966.96	17632.84	20309.87
HDPE	11494.05	10998.66	14046.08
PET & HDPE (nat)	18396.61	17840.66	27797.08
PET & HDPE (col)	27364.91	24474.84	35119.47
PET & HDPE	18892.00	17840.66	28855.68
	16358.73	6842.00	35119.47

Table A-6

Transportation Costs
(Fuller, 1994:interview)

		$	
	ave	low	high
PET	800.00	546.27	1200.10
HDPE (nat)	754.69	546.27	1000.10
HDPE (col)	154.69	146.27	200.20
HDPE	1000.10	600.00	1200.00
PET & HDPE (nat)	1554.69	1000.00	2200.10
PET & HDPE (col)	954.69	600.00	1400.10
PET & HDPE	1800.10	1146.27	2400.10
	1002.71	146.27	2400.10

Table A-7

Savings from Reduced SW Collection
(Fuller, 1994:interview)

		$	
(50% savings)	ave	low	high
PET	1500.00	900.00	2145.00
HDPE (nat)	1406.25	900.00	1950.00
HDPE (col)	281.25	180.00	390.00
HDPE	1687.50	1080.00	2340.00
PET & HDPE (nat)	2906.25	1800.00	4095.00
PET & HDPE (col)	1781.25	1080.00	2535.00
PET & HDPE	3187.50	1980.00	4485.00
	1821.43	180.00	4485.00

Table A-8

Savings from Reduced SW Disposal
(Fuller, 1994:interview)

		$/ton	
	ave	low	high
	95.00	40.00	150.00
		$	
	ave	low	high
PET	7600.00	2000.00	16500.00
HDPE (nat)	7125.00	2000.00	15000.00
HDPE (col)	1425.00	400.00	3000.00
HDPE	8550.00	2400.00	18000.00
PET & HDPE (nat)	14725.00	4000.00	31500.00
PET & HDPE (col)	9025.00	2400.00	19500.00
PET & HDPE	16150.00	4400.00	34500.00
	9228.57	400.00	34500.00

Appendix B

The decision support model was programmed using the DPL™ software package. The software package has two methods of programming, text and draw. The decision support model for this research was programmed using the draw feature. The DPL™ model was linked to an EXCEL™ spreadsheet to import values of the model variables (Appendix A). Figure B-1 shows the influence diagram of the decision support model that incorporates the cost categories into each step and shows the relationships and influences of each. Figures B-2 through B-6 define each cost category of the decision model.

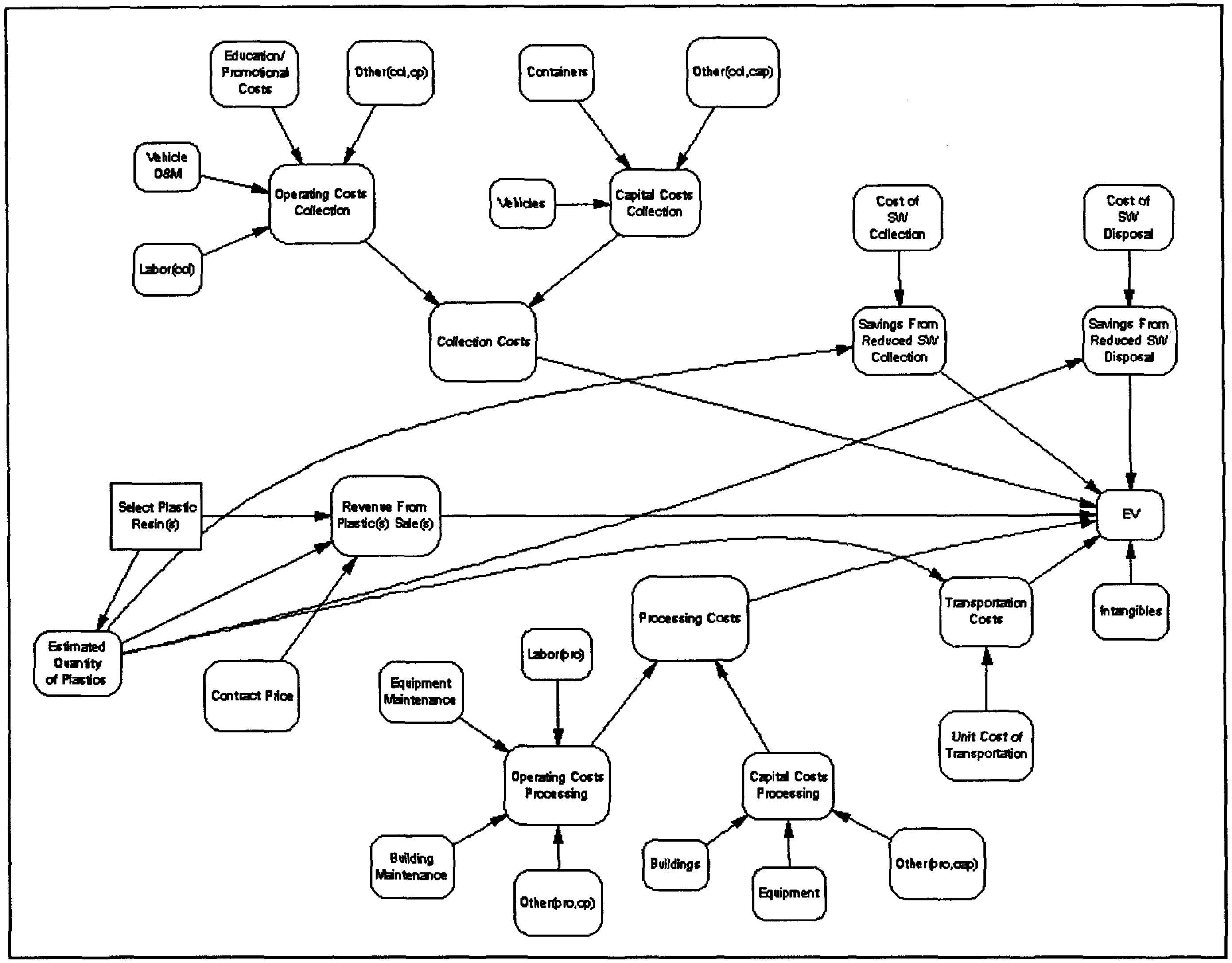


Figure B-1. Decision Support Model

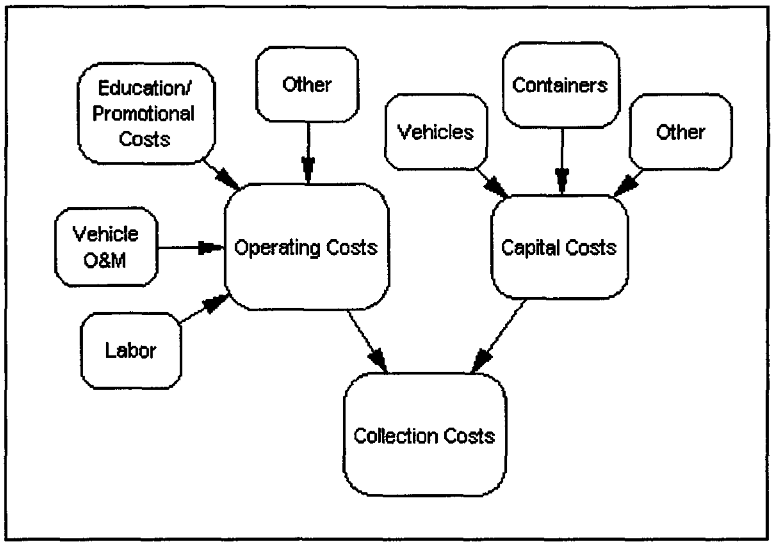


Figure B-2. Collection Costs

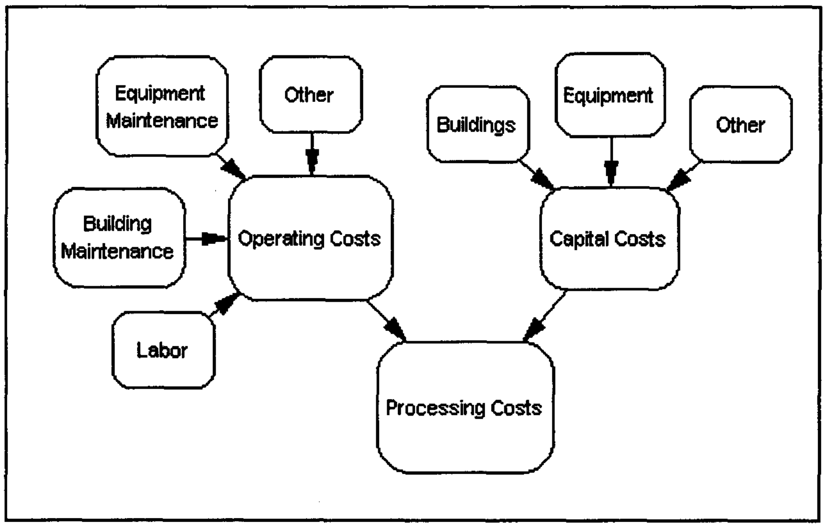


Figure B-3. Processing Costs

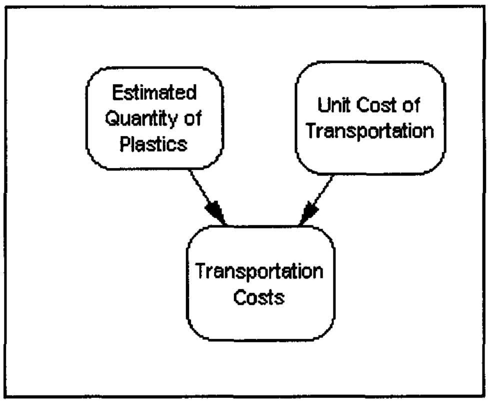


Figure B-4. Transportation Costs

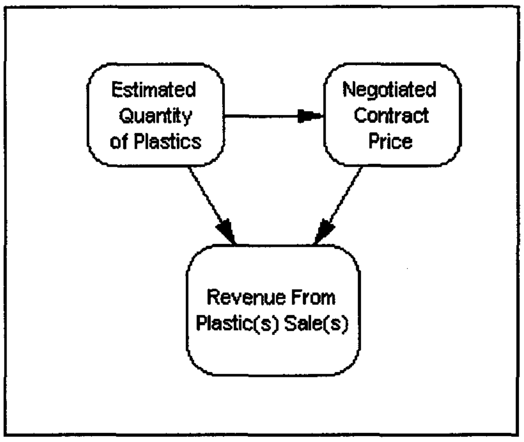


Figure B-5. Revenue from Sales

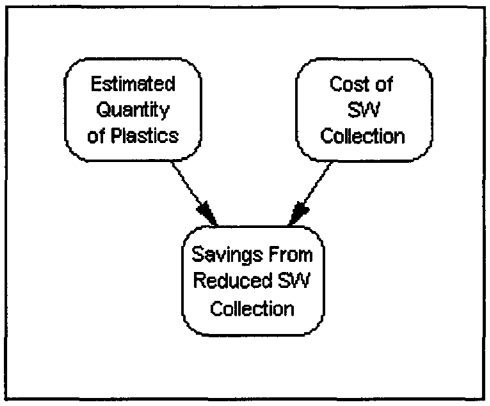


Figure B-6. Savings from Reduced SW Collection

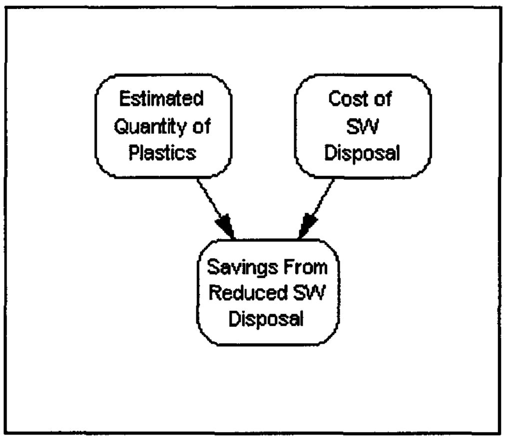


Figure B-7. Savings from Reduced SW Disposal

Appendix C

Appendix C describes how to use the model presented in the paper. The model was created using the DPL™ Advanced Version, a Microsoft Windows application.

Starting DPL™

To start DPL™, first start Windows. Then, using the mouse, double-click on the DPL™ icon. The first display seen is the Welcome screen. To move on, use the mouse to click on the OK button at the bottom of the screen. After closing the Welcome screen, the next display is the DPL™ Main window.

Loading the model

To load the model, first click on Draw from the Main menu. Next, insert the diskette into the appropriate drive. Choose the File Open from the Draw menu. A dialog box will appear. Under Drives, click on the underlined down arrow to enlarge the menu. Using the arrows, scroll to the appropriate drive designation and click on it using the mouse. The selected drive will be highlighted in blue. Next, under File Name, double-click on the file labeled "model.inf" to select and load it.

Inputting the data

To input the site-specific data, first select the appropriate node by clicking on it with the mouse. The color of the selected node will change to magenta. To cancel a selection, press ESC or click the mouse on another part of the drawing. Next, choose the Node Edit Data from the Draw menu. A dialog box will appear prompting for the new value. Enter the value and click on the OK button. Repeat this process until all data has been entered.

Analyzing the data

There are three types of analysis to be performed on the model: Decision Analysis, Value Sensitivity Comparison (Tornado Diagram), and Value Sensitivity Analysis (Rainbow Diagram).

Decision Analysis. To perform a decision analysis, choose the Run Decision Analysis from the Draw menu. DPL™ checks the model for correctness and consistency. If it finds an error, it will highlight the node causing the problem or open a dialog box prompting for the missing data. When the diagram is correct, the Decision Analysis dialog box will appear. Change the Number of intervals to zero by clicking on the down arrow. To begin the evaluation, click on the OK button. A dialog box will appear displaying the expected value associated with the model. Click on the OK button to open the window for the optimal decision policy.

The Decision Policy window displays the expected value for each alternative and identifies the optimal decision.

To save the decision policy, first choose View Text from the menu. Then, choose File Save As from the menu. In the dialog box, enter the name of the file to which to save the policy and then click on the OK button.

To continue with the analysis, click on the bar in the upper left-hand corner of the Decision Policy window and select Close. Press TAB to return to the influence diagram.

Value Sensitivity Comparison (Tornado Diagram). To perform a value sensitivity comparison, choose the Run Value Sensitivity Comparison (Tornado Diagram) from the Draw menu. A dialog box will appear prompting for the settings for the first sensitivity analysis. Under Value Name, select the variable to be analyzed by double-clicking on it using the mouse. Next, enter the low and high values by clicking on the appropriate box and then click on the OK button. DPL™ will then display a bar indicating the difference in the expected value.

To add additional variables to the same diagram, choose Add from the menu and repeat the previous steps. If there are to many sensitivity bars to display on the screen at once, a scroll bar at the right of the diagram allows viewing of all the bars.

To save the Tornado Diagram, choose the File Save As from the menu. In the dialog box, enter the name of the file to which to save the policy and then click on the OK button.

To continue with the analysis, click on the bar in the upper left-hand corner of the Value Sensitivity Comparison window and select Close.

Value Sensitivity Analysis (Rainbow Diagram). To perform a value sensitivity analysis, choose the Run Value Sensitivity Analysis (Rainbow Diagram) from the Draw menu. A dialog box will appear prompting for the settings for the first sensitivity analysis. Under Value Name, select the variable to be analyzed and click on it using the mouse. Enter the starting and ending values by clicking on the appropriate box. Next, enter 21 in the Number of values box and click on the OK button. DPL™ will then display a graph with the expected value along the vertical axis and the range of values for the sensitivity variable along the horizontal axis.

To save the Rainbow Diagram, choose Titles Save As from the menu. In the dialog box, enter the name of the file to which to save the policy and then click on the OK button.

To perform analysis on other variables, click on the bar in the upper left-hand corner of the Value Sensitivity Analysis window, select Close, and then repeat the previous steps.

Exiting DPL™

To exit the program, click on the bar in the upper left-hand corner of the Draw window and select Close. Again, click on the bar in the upper left-hand corner of the Main window and select Close. A dialog box will appear notifying of the end of the DPL™ session. Click on the OK button to exit.

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